DEVELOPMENT OF ENERGY EFFICIENT WSN PROTOCOL FOR PRECISION AGRICULTURE

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DEVELOPMENT OF ENERGY EFFICIENT WSN PROTOCOL FOR PRECISION AGRICULTURE

Thesis submitted in partial fulfilment

of the requirements for the degree of

MASTER OF TECHNOLOGY

in

COMPUTER SCIENCE & ENGINEERING

by

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Certificate

This is to certify that the work in the thesis entitled ***Development of Energy Efficient WSN Protocol for Precision Agriculture*** by ***Ganit Kumar*** is a record of an original research work carried out by him under my supervision and guidance in partial fulfilment of the require- ments for the award of the degree of Master of Technology in the Department of Computer Science and Engineering, National Institute of Technology Rourkela. Neither this thesis nor any part of it has been submitted for any degree or academic award elsewhere.

Place: NIT Rourkela
Date: May 27, 2015
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Acknowledgment

I am highly indebted to my guide Prof. (Mrs.) S. Chinara for giving me an opportunity to work under her able guidance. Like a true mentor, she motivated and inspired me through the entire duration of the work, without which this project could not have seen the light of the day.

I convey regards to all the other faculty members of the Department of Computer Science and Engineering, NIT Rourkela for their valuable guidance and advices at appropriate times. I would like to thank my friends for their help and assistance all through this project.

Last but not the least, I express my profound gratitude to the Almighty and my parents for their blessings and support without which this task could have never been accomplished.

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Authors Declaration

I hereby certify that all the work contained in this report is done by me unless otherwise acknowledged. Also, all of my work has not been previously submitted for any academic degree. All sources of quoted information have been acknowledged by means of appropriate references.

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Abstract

To meet the flaws associated with the traditional precision agriculture such as poor real-time data acquisition, smaller monitoring area, excessive manpower requirement, wireless sensor network (WSN) based precision agriculture has come into play. Proper agricultural practices result in good yield. These agricultural practices include varying crops and crop production techniques under different conditions. These conditions are soil moisture content, soil texture, etc.. A Wireless Sensor Network (WSN) is established with sensor nodes buried inside the soil to transmit the sensed data to the sink node or base station. Existing protocols are studied for their possibility for implementation into precision agriculture in this paper. A new protocol is proposed which imbibes the good features of both clusters and trees that enhances the network life time by reducing the per node energy consumption and maintains balance between energy consumption and energy disparity.

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Abbreviations

WSN	Wireless Sensor Network
PA	Precision Agriculture
DCP	Direct Communication Protocol
CTP	Collection Tree Protocol
LEACH	Low-Energy Adaptive Clustering Hierarchy
CHT	Cluster Head Tree
BS	Base Station
CH	Cluster Head
NOC	Number of Clusters

Chapter 1

Introduction

1.1 Precision Agriculture

Wikipedia defines Precision Agriculture as a farming management concept based on observing, measuring and responding to inter-field variability of crops. Farmers have been doing crop management to suit varying conditions like moisture content, humus content, soil texture etc. since ages for maximizing their production. But now with the advancement in the technology these varying conditions can be found more accurately. These different parameters are measured by the sensor nodes deployed in the field. These sensor nodes relay the data to the sink node or base station. There at the base station data is analyzed and appropriate decisions are taken. In short "Precision Farming" is an agriculture concept in which new technologies are used to predict the crop production parameters more precisely [1] .

Figure 1.1: A Football Field is shown under precision agriculture

Figure 1.2: An agricultural field under Precision Agriculture

1.2 Wireless Sensor Networks

If the agricultural land on which precision farming has to be done is very vast, then it is very difficult to deploy wired sensor nodes if a better protocol is not there. Here comes Wireless Sensor Network into the picture. A Wireless Sensor Network (WSN) is a network of spatially distributed wireless sensors to monitor physical or environmental conditions and to cooperatively pass their data through the network to a main location.
Wherever a WSN is there, there has to be an efficient protocol. Efficient Protocol means that it should be energy efficient, nodes should not die out more quickly, packet duplicity should be low. Keeping these criteria in mind, some protocols are discussed.
The main characteristics of wireless sensor network include:

1. It is easy to use.
2. It is scalable.
3. It has the capability to survive even if certain nodes is dead.
4. Power Consumption is the limiting constraint.

1.3 Routing in Wireless Sensor Networks

The aim of WSN in precision agriculture is to monitor an agricultural field. The main motive of a sensor node is to collect data from its part of the field, process them and then forward it to the Base Station. However, if sensor nodes will send the data directly to the base station obviously the farther nodes will consume more energy. To check this larger energy dissipation, more intermediate sensor nodes are made part of the path between those sensor nodes and the sink node. So, from Single-Hop direct communication, the path is now multi-hop.

According to the involvement pattern of sensors, routing protocols in WSN can be categorized as the following types.

A. Direct Communication

   In direct communication, each sensor node directly send their data to the base station. So, in the case when field is large, the farther nodes' battery will deplete most rapidly. Hence, this protocol is generally suited when field size is small because scalability is low. Example: DCP.

B. Chain Based

   All the sensor nodes form a chain using greedy technique. Generally chain formation is guided by base station. It starts from the farthest node which chooses closest node to form a chain. In this type of protocol, nodes closer to the base station consume more energy because they have to perform more data aggregation. Example: PEGASIS

C. Tree Based

   In this type of protocol, all the nodes form a tree with base station as the root. Hence some of the nodes are intermediate roots and some of them are leaf nodes. Tree formation is mostly based either on distance or link quality. Same as chain based, nodes closer to the root consume more energy. Example: CTP

D. Cluster Based

   In this type of protocol, some of the all the nodes group together to form a cluster. A cluster head is chosen among them. Non-cluster head nodes send their data to respective cluster heads which in turn forward the data to the base station. Energy disparity between the nodes is less in this type of protocol. Example: LEACH

1.4 Issues in designing WSN

There are some issues in the designing of routing protocols for WSNs due to various constraints in the network. WSNs suffer from the drawbacks of several network resources such as bandwidth, energy, storage and computation power. Some of the issues are listed below:

1. Battery

   Since any sensor nodes' lifetime depend on batteries, it is the most important issue in designing a routing protocol for any WSN. In some remote area, if a sensor node becomes dead, it is extremely difficult to replace that faulty node. Hence in such situation, having a better routing protocol is of utmost importance. If one node dies it affect the performance of other nodes as well which in turn increases the load on the whole network.

2. Location of Sensors

   In precision agriculture, nodes are generally fixed i.e. mobility is not there. However when mobility comes into factor as in other WSN applications, nodes are either tied with Global Positioning Systems or are located using signal strength(RSSI).

3. Scalability of the Network

   Routing protocols must be scalable i.e. its performance should not get hampered by the size of the network. In case of Precision Agriculture, even if field size is large, protocol should perform the same as it performed in a small field.

4. Deployment

   The way of deployment of sensor nodes in WSNs certainly affects the network's performance. Sensor nodes may be scattered randomly or may be placed in grid fashion or may be in uniform topology. When the sensor nodes distribution is not uniform, clusters should be formed by dividing the whole area into number of sub-regions.

5. Data Aggregation

   Various Data aggregation techniques aim to gather data in as efficient manner as possible to prolong the network's lifetime. Several algorithms exist to aggregate the data. Some of them are CMLDA, RFEC algorithm etc. Also, since packet loss increases with increases with increase in packet payload size, payload size should be kept as minimum as possible.

Chapter 2

Literature Review

With the deployment of WSN, precision agriculture has taken a front seat in the area of research. Precision agriculture is the science of precise understanding, estimating and evaluating the land and crop condition to apply the proper fertilizer and irrigation to it. WSN has become a boon for such precision agriculture. Gutierrez et al. [10] has done an intensive study for the automated irrigation system and have tested in Baja California Sur, Mexico for sage production. Wang et al. [11] provides architecture of intensive irrigated agriculture monitoring system based on wireless sensor networks in China. Abd El-kader et al. [12] showed how the use of precision agriculture techniques resulted in increase in crop yield and saving in fertilizer and irrigation water on potato crop in Egypt. They proposed APTEEN protocol which they found it to be most suitable strategy for precision farming. Sahota et al. [1] proposed a MAC protocol for Precision Farming and compared it with popular S-MAC protocol. They took into account drift in frequency of sensor nodes for wake-up synchronization.

2.1 Direct Communication

Direct Communication Protocol is the simplest protocol that can be implemented in Wireless Sensor network. Each Sensor node send its data directly to the sink node or the base station. So the only receptions that occur are at the base station. However, here distance comes into factor. If the sink node is situated at a considerable distance from the sensor nodes then more energy will be required to transmit the data.

This protocol is better either when base station is comparatively nearer to the sensor nodes or energy consumed in receiving is more than transmitting [1].

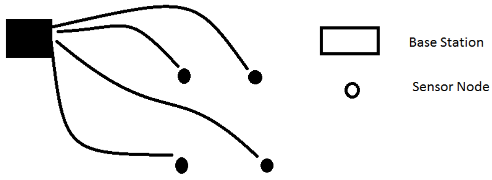

Figure 2.1: Direct Communication Protocol

Drawbacks of Direct Communication Protocol

1. Distance comes into the factor. As the distance of some of the nodes may be larger from the sink node, those nodes will consume more energy and as a result will die out more quickly.
2. Energy load will be more on the network affecting its performance.
3. Improper synchronization between the sensor nodes will result in huge packet loss.

2.2 Collection Tree Protocol

Whenever a sensor node has the data to send, it sends it up in the tree. Intermediate root nodes collect the data and forward it to their predecessor nodes. Ultimately the data reaches BS[3].

Algorithm

ETX is basis for routing. ETX is measure of expected transmissions required to transmit information between two different nodes. In a multi- hop route,

$$ETX_{Resultant} = \sum ETX_{individualhops}$$

The route which has lower ETX is preferred. A tree root always has an ETX of zero.

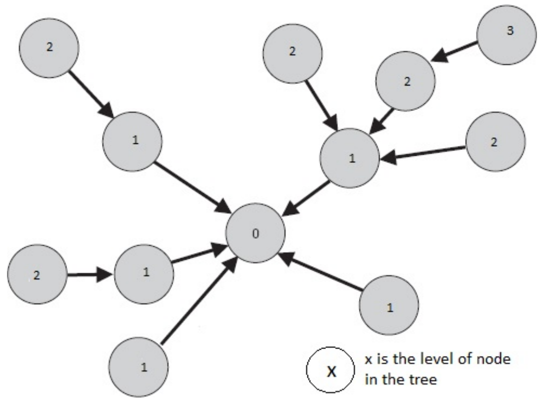

Figure 2.2: Cluster Tree Protocol

Drawbacks of Collection Tree Protocol

1. Some nodes use up more energy as compared to others. Those nodes are intermediate nodes. They have to do both receiving and sending job.
2. As a result of that those nodes can die out more quickly hampering the whole network.
3. Packet duplicity is much more higher.
4. There is no fixed number of intermediate nodes.

2.3 LEACH

LEACH stands for Low Energy adaptive clustering Hierarchy [2]. In this protocol, some of the sensor nodes are Cluster Heads and the Non-Cluster head nodes send their information to the Cluster Head nodes which in turn relay the information to the sink node. The number of Cluster Head nodes is decided prior to the set-up of the network by probability. After each round Cluster Head nodes change.
LEACH can be broadly classified into 4 phases:

1. Advertisement Phase : In this phase cluster heads advertise themselves.
2. Cluster Set-Up Phase : Non-cluster head nodes decide which cluster to join based on RSSI.
3. Schedule Creation Phase : TDMA schedule is broadcasted by CH node.
4. Data Transmission Phase : Data transfer takes place.

The random based probabilistic algorithm guarantees that a node which has become a cluster head in a round cannot become CH again in next (1/p) rounds.

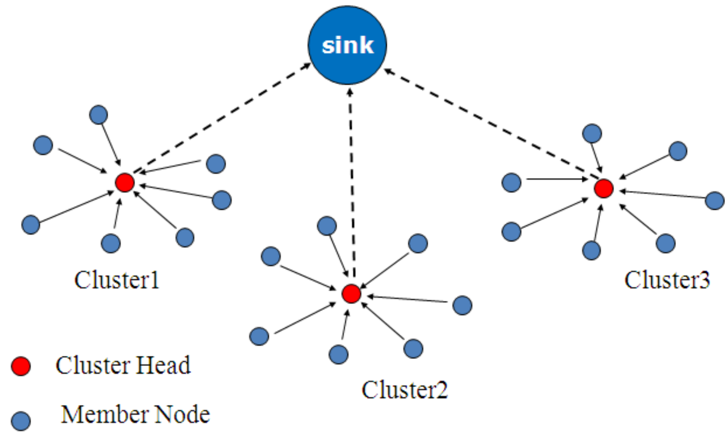

Figure 2.3: A figure showing clusters with cluster head, Non-cluster head nodes and Sink Node

$$T(n) = \begin{cases} \dfrac{P}{1 - P * (r \; mod \; P^{-1})} & \text{if } \forall \; n \in G \\ 0 & \text{if } \forall \; n \notin G \end{cases} \tag{2.1}$$

Drawbacks of LEACH

1. Less energy efficient than Collection Tree Protocol(CTP)
2. If the sink node is at large distance, more energy is consumed by the Cluster Head nodes to transmit their data.
3. Randomized cluster head selection leads to energy disparity.

Algorithm 1 LEACH Algorithm

Require: CLUSTERHEADS=[], r=Current Round, P=Probability

procedure CH–ELECTION
    for each node $i \in N$ **do**
        if $i \in G$ where G is set of nodes which are not CHs in (1/p) rounds **then**
            if $rand(0,1) \leq \frac{P}{1-P*(r \ mod \ P^{-1})}$ **then**
                Add i in CLUSTERHEADS
            end if
        end if
    end for
    for each node $i \in$ CLUSTERHEADS **do**
        Broadcast Hello Packet to all the other nodes
    end for
end procedure ▷ The next procedure is for Steady State Phase
procedure STEADY STATE PHASE
    for each node $i \notin$ CLUSTERHEADS **do**
        Send Data to Corresponding CH
    end for
    for each node $i \in$ CLUSTERHEADS **do**
        Receive the data
        Bind the data
        Send to the Base Station
    end for
end procedure

Chapter 3

Proposed Cluster Head Tree Protocol

3.1 Motivation

The proposed algorithm is a combination of LEACH and CTP. It has the good features of both LEACH and CTP. LEACH has a good feature that all of the sensor nodes consume almost same amount of energy. Collection Tree Protocol has a good feature that the average amount of energy consumed is comparatively less than that of LEACH and Direct Communication Protocol. Amalgamation of these two protocols will give us a new protocol. Let us call the new protocol as Cluster Head Tree (CHT) Protocol.

3.2 Architecture of the Proposed Protocol

There will be cluster head nodes and non-cluster head nodes same as in LEACH. But in this protocol all the cluster head nodes will form a tree. So, one cluster head node will forward the aggregated data to the next cluster head in the multi-hop.

Basic Features

- Every node has a distinct ID.
- Base Station is placed at corner of the field.
- Base Station has infinite amount of energy.
- All the sensor nodes are capable of sending and receiving data.
- All the sensor nodes have the ability to put themselves in idle state when no work is being done.

- All the sensor nodes are in the communication range of the base station.
- All the sensor nodes are fixed and homogeneous.

Initialization

All the sensor nodes report their initial energy and their location to the base station. On the basis of that, base station forms a distance matrix, residual energy matrix.

$$\begin{pmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{n1} & \cdots & d_{nn} \end{pmatrix}$$

Distance Matrix

$$\begin{pmatrix} E_1 & \cdots & E_i & \cdots & E_n \end{pmatrix}$$

Residual Energy Matrix

Cluster Formation

Sink node decides the cluster formation. It has the distance matrix with the help of which it forms cluster. It has the residual energy matrix which helps in choosing the maximum energy node as the cluster head.

Clusters are formed using a new method. Let us name it as **Radial Clustering**. In this, the field is radially divided into a number of partitions such that each partition has same area. Base Station is placed at the corner of the field.

A general estimation is used for determining the number of clusters.

$$\text{Optimal Number of Clusters (NOC)} = \sqrt{\frac{n}{2}}$$

where n is the total number of nodes.

The distance of farthest node is found using distance matrix. Lets us call it R. Each variable radius is represented by r_i. r_0 is 0. r_1 is $R\sqrt{\frac{1}{NOC}}$. The general formula is derived below.

So, for dividing a quadrant into equal sized radial partitions with one corner as center, we have

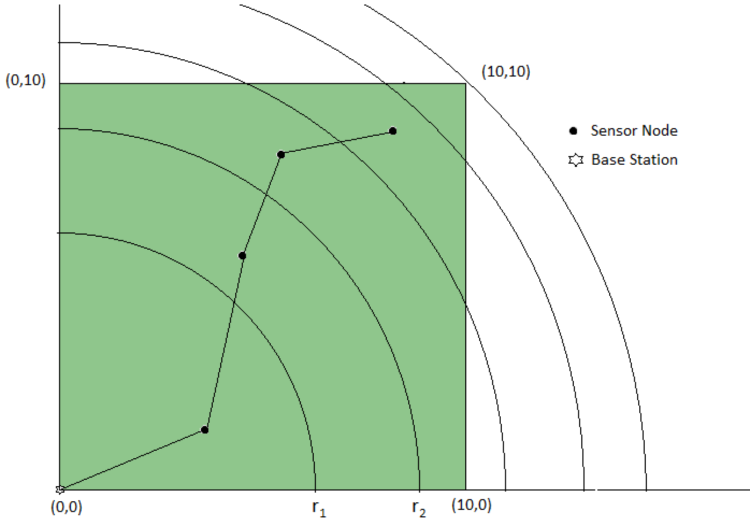

Figure 3.1: Radial Clustering

$$\frac{\frac{\pi R^2}{4}}{NOC} = \frac{\pi(r_i^2 - r_{i-1}^2)}{4} \tag{3.1}$$

$$\Rightarrow \frac{R^2}{NOC} = (r_i^2 - r_{i-1}^2) \tag{3.2}$$

$$\Rightarrow r_i = R\sqrt{\frac{i}{NOC}} \tag{3.3}$$

For the partitions having inner radius greater than dimension of the field, they are merged into one.NOC is accordingly updated. For the given example figure of (10x10) field and initial NOC of 5, $r_1 = 6.32$, $r_2 = 8.94$, $r_3 = 10.95$, $r_4 = 12.64$, $r_5 = 14.14$. Hence, partition 4 and 5 are merged to form one partition. New NOC will be 4.

Clusters formed are numbered from 1 .. to .. Optimal number of clusters. Thereafter each node is associated with a cluster. Thus, Unique Cluster Matrix is formed.

$$\begin{pmatrix} C_1 & \cdots & C_i & \cdots & C_n \end{pmatrix}$$

where $C_i = \{1, 2, ..., NOC\}$

Sink node selects the maximum energy node in each cluster as the cluster head. If for two nodes energies are same, then the node having lower NODE_ID is chosen as the cluster head. This gives rise to Cluster Head Matrix.

$$\begin{pmatrix} CH_1 & \cdots & CH_i & \cdots & C_{NOC} \end{pmatrix}$$

where $CH_i = \{1, 2, ..., n\}$

Tree Formation

After finding the cluster heads, sink node tries to form a tree of those nodes. Tree is minimum spanning tree with root at sink node.

Precedence matrix is formed after the tree formation is complete.

$$\begin{pmatrix} PRED_1 & \cdots & PRED_i & \cdots & PRED_{NOC} \end{pmatrix}$$

where $PRED_i = \{1, 2, ..., n, SinkNode\}$

Sink node broadcasts the distance matrix, unique cluster matrix, cluster head matrix and precedence matrix to all the nodes.

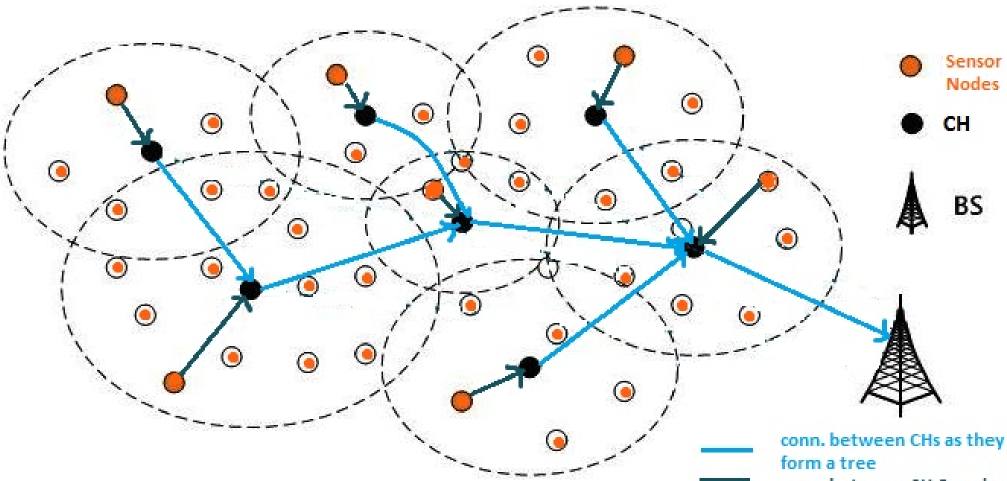

Figure 3.2: A figure showing proposed Cluster Head Tree Protocol

3.3 Packet Format

NODE ID	Len	Data....

Packet Format of Non-Cluster Head Node

Non-Cluster head nodes have simple packet format. It consists of their ID, Length of the data and the data. From the cluster head matrix and Unique Cluster Matrix broadcast-ed by the Sink node, they will choose their respective cluster heads and send the data.

NODE ID	Precedent NODE ID	Len	CHILD ID 1	Len	CHILD ID 2	Len	....	Data....

Packet Format of Cluster Head Node

Cluster Head node receives data from each non-cluster head nodes. For each receive, it incorporates the NODE ID from which it has received, the length of the data and the data itself to its packet. Its packet also includes the precedent node to which it has to forward the data. The aggregated data is forwarded to parent node which finally is sent to the base station. Base station has all the information about the distance between the nodes, their residual energy, cluster heads etc. Using these information, Base Station updates its residual energy matrix.

3.4 Energy Consumption

For each Transmit

$$EnergyConsumed = (ETX * l) + \begin{cases} (EMP * l * d^4) & \text{if } d < d_0 \\ (EFS * l * d^2) & \text{if } d \geq d_0 \end{cases} \tag{3.4}$$

For each Receive

$$EnergyConsumed = (ERX * l) \tag{3.5}$$

Each of the variables are defined in sec 4.2.2.

3.5 Benefits of the Proposed Protocol

Earlier in LEACH, if a cluster head is very far away from the sink node, it would consume more energy to transmit the data to the base station. But in the proposed CHT Protocol, that cluster head will send the data to the next cluster head, which in turn pass it to the base station or next nearest cluster head whosoever has a less distance, thereby consuming less energy.

Algorithm 2 CHT Algorithm

```
procedure INITIALIZATION
    for each node i ∈ N do
        Send location and initial energy to the base station
    end for
    Base Station forms Distance Matrix and Residual Energy Matrix
end procedure
procedure CLUSTER FORMATION PHASE
    Base Station performs Radial Clustering algorithm and form Unique Cluster Matrix
    CLUSTERHEADS=[]
    for each cluster i ∈ NOC do
        BS select the node n with maximum energy and add it to CLUSTERHEADS
    end for
end procedure
procedure TREE FORMATION PHASE
    Base Station forms MST among Cluster Head nodes and forms Precedence Matrix
    BS broadcasts Unique Cluster Matrix, Cluster Head Matrix to all the nodes
end procedure
procedure STEADY STATE PHASE
    for each node i ∈ n do
        Receive broadcasted message from Base Station
        if i ∉ CLUSTERHEADS then
            Decide the respective cluster head
        else
            Decide the predecessor Node
        end if
    end for
    for each node i ∉ CLUSTERHEADS do
        Send Data to respective cluster heads
    end for
    for each node i ∈ CLUSTERHEADS do
        Receive , Bind and Forward the data to the predecessor node
    end for
end procedure
```

Chapter 4

Implementation

4.1 TinyOS

The implementation of the proposed protocol and the existing protocols for a healthy comparison is done in TinyOS.

4.1.1 What is TinyOS?

TinyOS is a free and Open-Source Operating System designed for wireless devices [6]. It is an embedded operating system written in nesC programming language as a set of cooperating tasks and processes. It has been developed to efficiently work on different mote platforms. Embedded Operating System run inside the mote.

TinyOS was initially released in year 2000. Latest version in use is v2.1.3/2013.

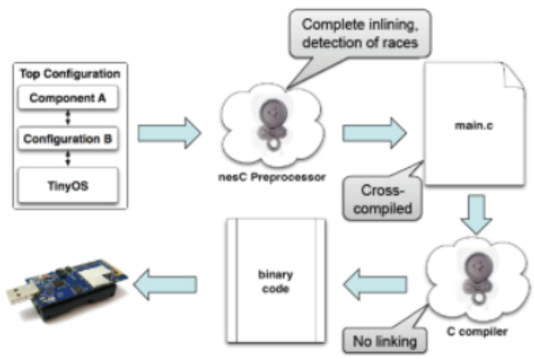

Figure 4.1: Stages of Compilation of TInyOS programs

Different TinyOS Concepts

TinyOS/nesC Concepts	Description
Application	Two or more components wired together to a run-time executable
Component	It is the building block for nesC applications. Components can provide and use applications. There are two types of components: Modules and Configurations.
Module	A component that implements interfaces
Configuration	A component that wires other components together, connecting interfaces used by the various components
Interface	A definition of the interaction of two components

Table 4.1: TinyOS concepts

Split-Phase Execution

Split-phase execution means that upcall is separated from downcall. For example if a node calls a method `call AMSend.Send(packet)`, it is immediately returned. It doesn't wait for the `SendDone()` to be completed. Both are asynchronous from each other. The reason it is so designed is that Sending is packet is a tedious process and it may take a lot of time. So, to keep the node do other task meanwhile it is immediately returned.

4.1.2 TOSSIM

TOSSIM simulates entire TinyOS applications [8]. It is a Command Line Interface (CLI) Simulator. It works by replacing components with simulation implementation.
TOSSIM support two programming interface:

- C++
- Python

4.1.3 JTOSSIM

It is a Graphical User Interface (GUI) Simulator. Underlying architecture is same as that of TOSSIM.

4.1.4 PowerTossimZ

PowerTossimZ is a plugin which models energy consumption [9]. It is an improvement over PowerTossim. PowerTossim was for TinyOS 1.x. So, an improvement was necessary. In addition to that PowerTossim could not simulate MicaZ motes.
PowerTossimZ is based on a trace model. A debugging channel called ENERGY_HANDLER is added to the python simulation code with the name of the output trace file. PowerTossimZ generates the traces in the file which looks like the following:-

Thereafter postprocessor comes into the picture. It can run in two modes.

- Silent Mode: The Trace file that is generated during simulation is analyzed and the final state of the battery of different nodes is reported at the end in a file called PowerCurse.
- Verbose Mode: For each and every line in the generated trace file, battery state is reported but only after the generation of the trace file.

4.1.5 Hardware Platforms

There are many simulation environments available for deploying TinyOS programs. Most commonly used platforms are telosb, mica, micaZ.

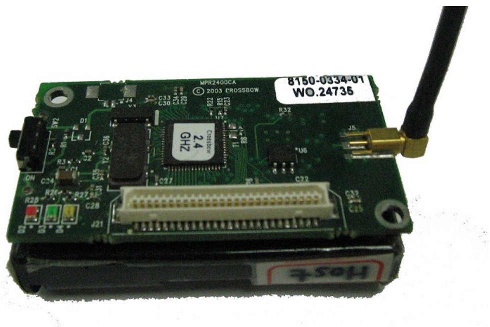

Figure 4.2: A Micaz Mote

All the simulation that has been done in the whole project is on MicaZ except in energy limiting conditions.

Specifications of MicaZ:

- 7.3728 MHz Clock
- 128 KB of program memory
- User Interface : 3 programmable LEDs (Red, Blue, Green)
- Radio : Chipcons CC2420
- 250 kbps data rate radio

4.1.6 Simulation Parameters

VOLTAGE	3.0 V	CPU FREQ	7382800 Hz
CPU ACTIVE	8.93 mA	RADIO TX	17.4 mA
CPU IDLE	4.93 mA	RADIO RX	19.7 mA
CPU POWER DOWN	0.0003 mA	RADIO OFF	0 mA
CPU POWER SAVE	0.009 mA	LED	2.2 mA
CPU STANDBY	1 mA	SENSOR BOARD	0.69 mA

Table 4.2: Simulation Parameters (Infinite Energy Environment)

4.2 Implementation in Energy Constrained Environment

The implementation of the proposed protocol and the existing protocols in energy limiting environment is done in MATLAB.

4.2.1 Why TinyOS cannot be used in this Environment?

The implementation of the protocols in energy limiting environment is not possible in TinyOS. TinyOS calculates the energy after the simulation of the program is complete i.e. at run-time we cannot get the energy of a node. In both Silent and verbose modes, the residual energy is calculated from the trace file produced during the simulation.

By executing a protocol in energy limiting environment, we would be able to get the information about when the first node dies and when the last node dies. We can also get the information that which operation costed more energy than others.

Also at the run time position of nodes cannot be determined. So, to implement LEACH, rather than distance, RSSI (Received Signal Strength indication) is used as basis for forming clusters. Further than that, in proposed CHT algorithm(for implementation in TinyOS), Clusters were formed by LEACH probabilistic algorithm not by using Radial Clustering because of the same reason. Because of the above reasons, MATLAB was used to simulate in energy constrained environment.

4.2.2 Simulation Parameters (Energy Limiting Environment)

E_0	0.5 J
E_{TX}	50 nJ/bit
E_{RX}	50 nJ/bit
E_{fs}	10 pJ/bit/m^2
E_{mp}	0.0013 pJ/bit/m^4
E_{DA}	50 nJ/bit

Table 4.3: Simulation Parameters (Constrained Energy Environment)

E_0	:	Initial Battery Energy
E_{TX}&E_{RX}	:	For powering Transmitter and Receiver Circuitry
E_{mp}	:	Energy Consumption of Amplifier
E_{fs}	:	Energy Consumption of Transceiver
E_{DA}	:	Data Aggregation Energy

Chapter 5

Results and Analysis

5.1 Direct Communication Protocol - Observations and Results

The following observations are common and are valid for all the protocols.

A. Firing Time of Sensor Nodes

When Firing Interval was set to `call MilliTimer.StartPeriodic(250)` average packet loss was about 20%. However, when the firing interval of the sensor nodes was set to `call MilliTimer.StartPeriodic(250+(10*TOS_NODE_ID))` average packet loss was about 6%. This infers that sensor nodes should have varying time intervals to reduce the packet loss.

B. Effect of Path Gain

While setting network configuration for TOSSIM, when the path gain was set to -110 dB then the sink node was not able to receive any packet. Since the path gain is actually loss, minus sign is preceded to the gain.

C. Payload Size of Packets

With the increase in the payload size, packet loss increased. This infers that data size to be transmitted from sensor nodes should be kept as minimum as possible

5.2 LEACH Results

- Effect of varying Probabilities

  As the probability is increased, the number of cluster heads will increase. Hence the number of non-cluster head sensor nodes will decrease. As a result, the number of sent packets will decrease considerably. But on the other hand, Packet Loss percentage will also decrease as there are more number of cluster heads so less interference and collision will be there.

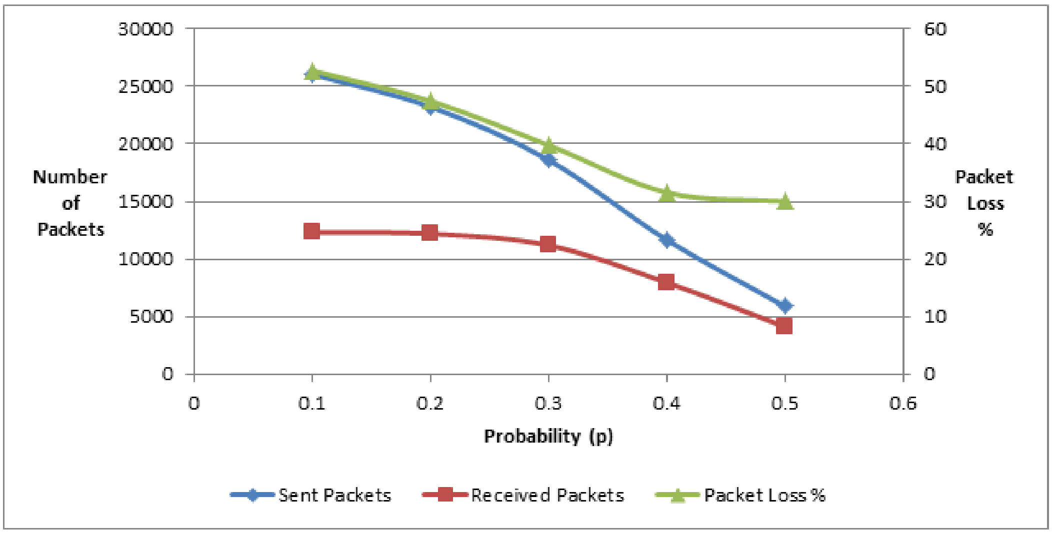

Figure 5.1: LEACH on varying probabilities

When the probability was 0.1, total packets sent were 26065 and total packets received were 12452 with packet loss percentage 52.23%. When the probability was 0.2, total packets sent were 23228 and total packets received were 12452 with packet loss percentage 47.62

5.3 Energy Comparison of the Protocols

Comparison of Energy consumed by different nodes in LEACH, DCP, CTP and CHT

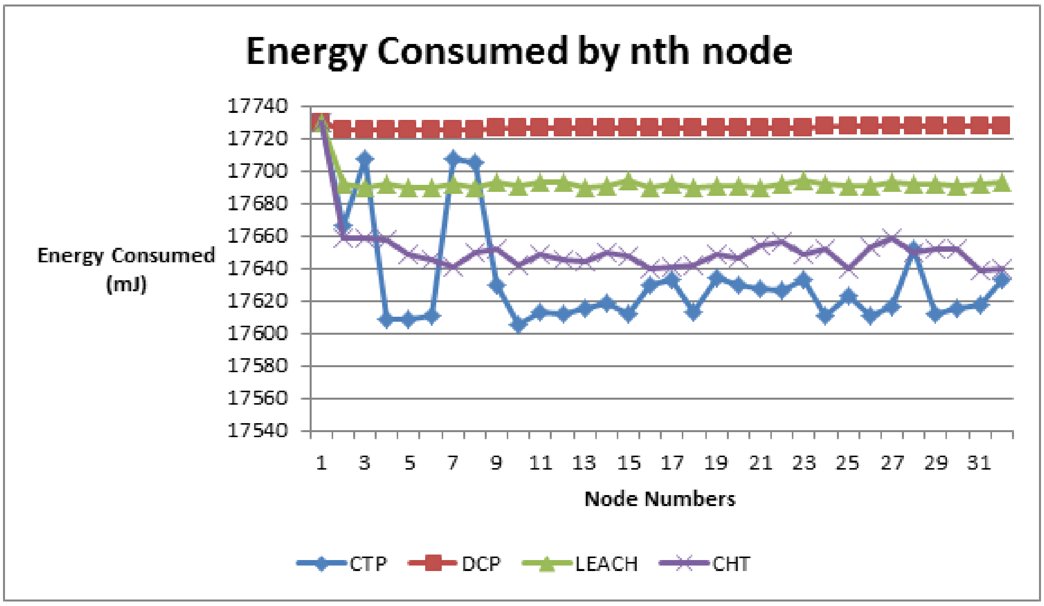

Figure 5.2: Energy Comparision of Protocols

- Average energy ($\overline{E}_{DCP}$) consumed by all the nodes in Direct Communication Protocol is 17726.1875 mJ.
- Average energy ($\overline{E}_{CTP}$) consumed by all the nodes in Collection Tree Protocol (CTP) is 17633.2812 mJ.
- Average energy ($\overline{E}_{LEACH}$) consumed by all the nodes in LEACH is 17692.75 mJ.
- Average energy ($\overline{E}_{CHT}$)consumed by all the nodes in Cluster Head Tree (CHT) Protocol is 17650.9375 mJ [1].
- Base Station consumes the highest amount of energy.
- Cluster Head Tree (CHT) protocol is better than LEACH.

Average energy consumed by nodes in LEACH is lower than that of DCP but higher than that of CTP. In both analogies, distance comes into factor. CTP is more effective because of the comparatively smaller distance that the data has to be transmitted. But the standard deviation of the energy consumed by the nodes in CTP is higher.

[1]Since the protocol was executed in TinyOS, LEACH probabilistic algorithm was used to form clusters. Also the minimum energy heuristic was not used. See Sec 4.2.1 for more details. The complete CHT protocol results are in Sec. 5.5

Standard Deviation of the Energy consumed by the nodes

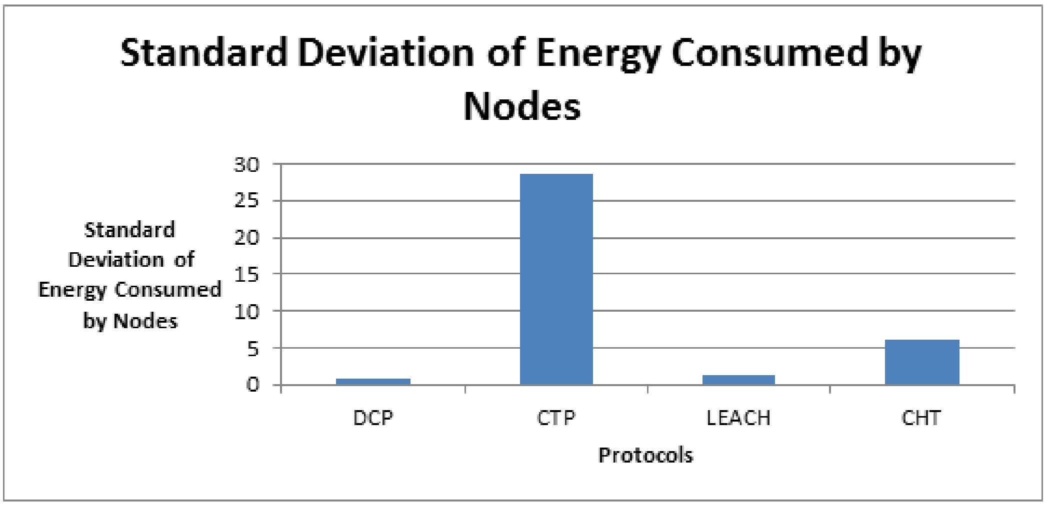

Figure 5.3: Standard Deviation (σ) of Energy Consumed by the nodes

LEACH is advancement over CTP[2]. in the respect that the standard deviation of the energy consumed by the nodes in LEACH is less than that of CTP. This means that the energy consumed by the sensor nodes in LEACH is more even. This will prevent the some of the nodes to die out more quickly. However, the average energy consumed by the sensor nodes in LEACH is higher than that of CTP. This is because of the distance.

In Fig. 5.2, we can easily see that some of the nodes in CTP consume way more energy than others. Also, all the protocols have been executed only for 300 seconds. As the time of execution will increase energy disparity between the nodes will increase, resulting in some of the nodes to fail in the midst of working if energy of the mote is the limiting factor.

The proposed Cluster Head Tree (CHT) protocol however maintains a balance between energy consumption and energy disparity. Its energy disparity between the nodes is higher than LEACH but consumes way less energy than LEACH.

[2]Since the protocol was executed in TinyOS, LEACH probabilistic algorithm was used to form clusters. Also the minimum energy heuristic was not used. See Sec 4.2.1 for more details. The complete CHT protocol results are in Sec. 5.5

5.4 CHT Results

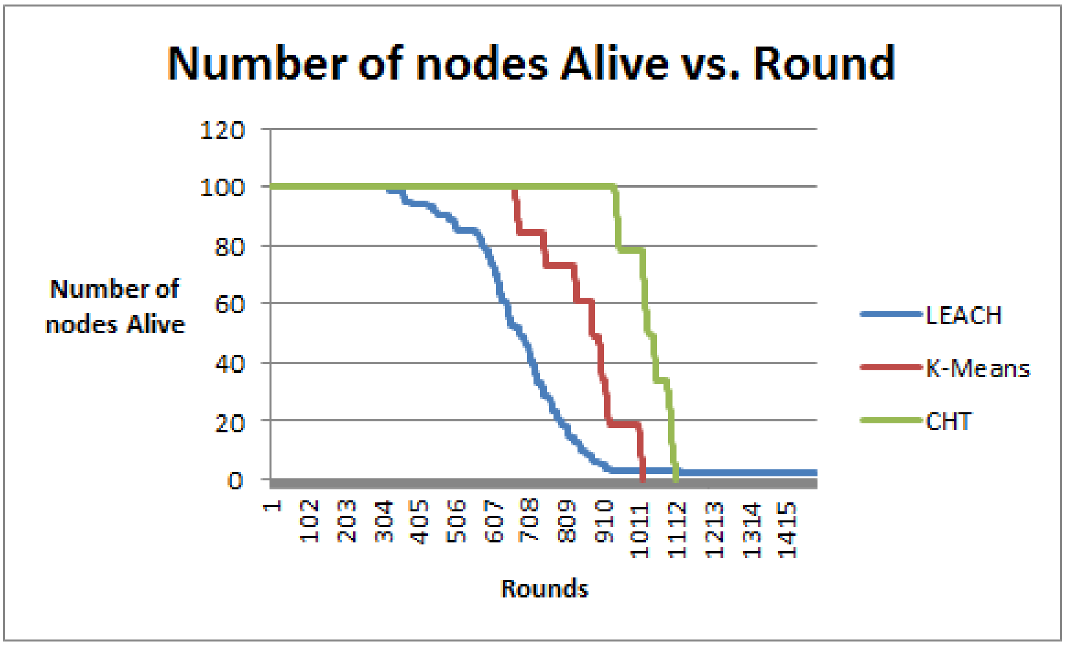

Figure 5.4: CHT : Number of nodes alive vs Round

As can be seen that Network lifetime is prolonged in proposed CHT protocol that both LEACH and K-Means.

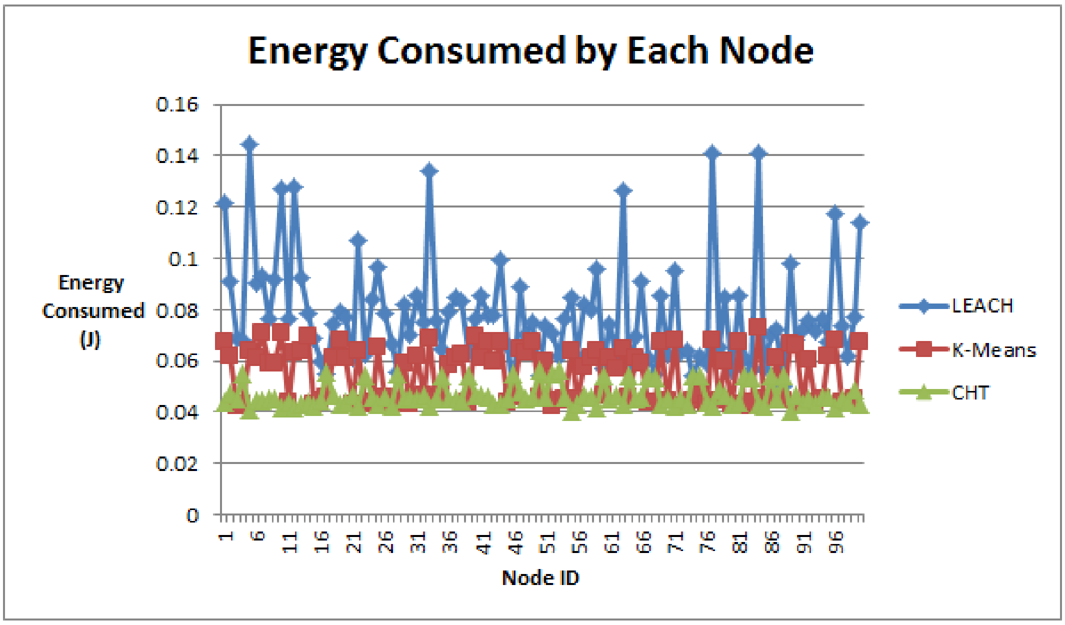

Figure 5.5: CHT : Energy Consumed by each node

Initial Energy of all the nodes was 0.5 Joule. This data of energy consumed by the nodes is taken after 100 rounds. As can be seen that energy consumption has some high peaks in case LEACH. This is due to probabilistic Cluster Head selection and large distance of some of the nodes from the BS. In case of K-Means with maximum energy Cluster Head selection, energy consumption is more even. But energy is much more even than K-Means in CHT because of tree formation of Cluster Heads which reduces the distance.

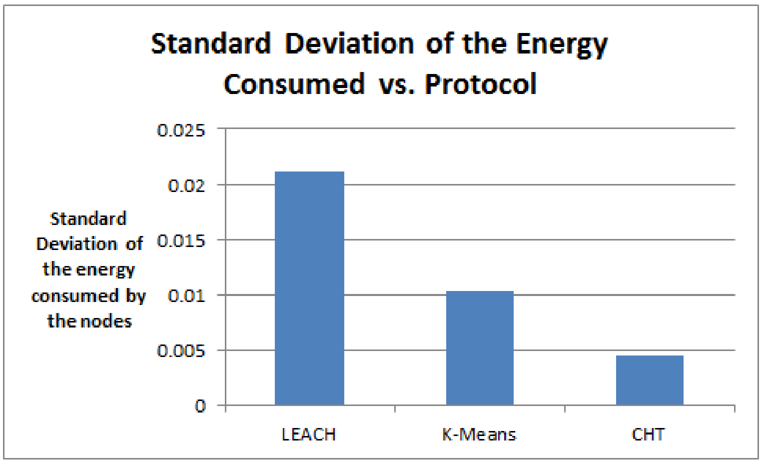

Figure 5.6: CHT : Standard Deviation of Energy (σ) Consumed by the nodes vs Protocol

All the graphs in this section are plotted from the results obtained by simulation in MATLAB (Energy Constrained Environment).

As can be seen from the above graphs of complete CHT Protocol, in addition to prolonging the lifetime of the network, it has also reduced the energy disparity among the nodes. Since all the nodes are considered to be homogeneous, this advancement in equal energy consumption will be of great help as there are no advanced nodes. If there would have been advanced nodes, energy disparity would not have been an issue. But at the same time advance nodes cost more which will eventually increase the cost to set up the network.

Chapter 6

Conclusion

In this paper, we considered different protocols for implementing Wireless Sensor Network for precision agriculture. There are so many challenges for deploying a network in agricultural field. The vast size of the field, real time working, and energy consumption of the nodes are some of them. We considered four protocols viz. Direct Communication Protocol, Collection Tree Protocol, LEACH and proposed Cluster Head Tree (CHT) protocol. Each protocol has its own advantages and disadvantages. While Direct Communication Protocol is the worst one in terms of average energy consumption by the nodes, Collection Tree Protocol is the most efficient in this respect. But the disparity of the energy consumption by the nodes in CTP is much more higher than LEACH. This may result in some of the nodes dying out more quickly. Once a node dies, it will hamper the whole network. Therefore the proposed protocol is needed which maintains balance between energy disparity and energy consumption. Formation of tree of the cluster head nodes will result in lessening the distance for transmission, thereby resulting in less consumption of the energy. The protocol was tested in different topologies and different simulators and they all augur well proposed hypothesis. Network lifetime is considerably prolonged and energy disparity is also reduced.

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Dissemination of Work

Accepted

1. Ganit Kumar and S. Chinara, Development of Energy Efficient Wireless Sensor Networks Protocol for Precision Agriculture, Journal of Basic and Applied Engineering Research, Volume 2, Number 5; January-March, 2015, pp. 360-364